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5. SOIL INGESTION AND PICA

5.1 INTRODUCTION

The ingestion of soil is a potential source of human exposure to toxicants. The potential for exposure to contaminants via this source is greater for children because they are more likely to ingest more soil than adults as a result of behavioral patterns present during childhood. Inadvertent soil ingestion among children may occur through the mouthing of objects or hands. Mouthing behavior is considered to be a normal phase of childhood development. Deliberate soil ingestion is defined as pica and is considered to be relatively uncommon. Because normal, inadvertent soil ingestion is more prevalent and data for individuals with pica behavior are limited, this section focuses primarily on normal soil ingestion that occurs as a result of mouthing or unintentional hand-to-mouth activity.

Several studies have been conducted to estimate the amount of soil ingested by children. Most of the early studies attempted to estimate the amount of soil ingested by measuring the amount of dirt present on children's hands and making generalizations based on behavior. More recently, soil intake studies have been conducted using a methodology that measures trace elements in feces and soil that are believed to be poorly absorbed in the gut. These measurements are used to estimate the amount of soil ingested over a specified time period. The available studies on soil intake are summarized in the following sections. Recommended intake rates are based on the results of key studies presented in the *Exposure Factors Handbook* and summarized here. Relevant information on the prevalence of pica and intake among individuals exhibiting pica behavior is also presented.

5.2 SOIL INTAKE STUDIES

Binder et al. (1986) - Estimating Soil Ingestion: Use of Tracer Elements in Estimating the Amount of Soil Ingested by Young Children - Binder et al. (1986) studied the ingestion of soil among children 1 to 3 years of age who wore diapers using a tracer technique modified from a method previously used to measure soil ingestion among grazing animals. The children were studied during the summer of 1984 as part of a larger study of residents living near a lead smelter in East Helena, Montana. Soiled diapers were collected over a 3-day period from 65 children (42 males and 23 females), and composited samples of soil were obtained from the children's yards. Both excreta and soil samples were analyzed for aluminum, silicon, and titanium. These elements were found in soil, but were thought to be poorly absorbed in the gut and to have been present in the diet only in limited quantities. This made them useful tracers for estimating soil intake. Excreta measurements were obtained for 59 of the children. Soil ingestion by each child was estimated based on each of the three tracer elements using a standard assumed fecal dry weight of 15 g/day, and the following equation:

$$T_{i,e} = \frac{f_{i,e} \times F_i}{s_{i,e}} \tag{5-1}$$

where:

$T_{i,e}$ = estimated soil ingestion for child i based on element e (g/day);
$f_{i,e}$ = concentration of element e in fecal sample of child i (mg/g);
F_i = fecal dry weight (g/day); and
$S_{i,e}$ = concentration of element e in child i's yard soil (mg/g).

The analysis conducted by Binder et al. (1986) assumed that: (1) the tracer elements were neither lost nor introduced during sample processing; (2) the soil ingested by children originates primarily from their own yards; and (3) that absorption of the tracer elements by children occurred in only small amounts. The study did not distinguish between ingestion of soil and housedust nor did it account for the presence of the tracer elements in ingested foods or medicines.

The arithmetic mean quantity of soil ingested by the children in the Binder et al. (1986) study was estimated to be 181 mg/day (range 25 to 1,324) based on the aluminum tracer; 184 mg/day (range 31 to 799) based on the silicon tracer; and 1,834 mg/day (range 4 to 17,076) based on the titanium tracer (Table 5-1). The overall mean soil ingestion estimate based on the minimum of the three individual tracer estimates for each child was 108 mg/day (range 4 to 708). The 95th percentile values for aluminum, silicon, and titanium were 584 mg/day, 578 mg/day, and 9,590 mg/day, respectively. The 95th percentile value based on the minimum of the three individual tracer estimates for each child was 386 mg/day.

The authors were not able to explain the difference between the results for titanium and for the other two elements, but speculated that unrecognized sources of titanium in the diet or in the laboratory processing of stool samples may have accounted for the increased levels. The frequency distribution graph of soil ingestion estimates based on titanium shows that a group of 21 children had particularly high titanium values (i.e., >1,000 mg/day). The remainder of the children showed titanium ingestion estimates at lower levels, with a distribution more comparable to that of the other elements.

The advantages of this study are that a relatively large number of children were studied and tracer elements were used to estimate soil ingestion. However, the children studied may not be representative of the U.S. population and the study did not account for tracers ingested via foods or medicines. Also, the use of an assumed fecal weight instead of actual fecal weights may have biased the results of this study. Finally, because of the short-term nature of the survey, soil intake estimates may not be entirely representative of long-term behavior, especially at the upper-end of the distribution of intake.

Clausing et al. (1987) - A Method for Estimating Soil Ingestion by Children - Clausing et al. (1987) conducted a soil ingestion study with Dutch children using a tracer element methodology similar to that of Binder et al. (1986). Aluminum, titanium, and acid-insoluble residue (AIR) contents were determined for fecal samples from children, aged 2 to 4 years, attending a nursery school, and for samples of playground dirt at that school. Twenty-seven daily fecal samples were obtained over a 5-day period for the 18 children examined. Using the average soil concentrations present at the school, and assuming a standard fecal dry weight of 10 g/day, Clausing et al. (1987) estimated soil ingestion for each tracer. Clausing et al. (1987) also collected eight daily fecal samples from six hospitalized, bedridden children. These children served as a control group, representing children who had very limited access to soil.

The average quantity of soil ingested by the school children in this study was as follows: 230 mg/day (range 23 to 979 mg/day) for aluminum; 129 mg/day (range 48 to 362 mg/day) for AIR; and 1,430 mg/day (range 64 to 11,620 mg/day) for titanium (Table 5-2). As in the Binder et al. (1986) study, a fraction of the children (6/19) showed titanium values well above 1,000 mg/day, with most of the remaining children showing substantially lower values. Based on the Limiting Tracer Method (LTM), mean soil intake was estimated to be 105 mg/day with a population standard deviation of 67 mg/day (range 23 to 362 mg/day). Use of the LTM assumed that "the maximum amount of soil ingested corresponded with the lowest estimate from the three tracers" (Clausing et al., 1987). Geometric mean soil intake was estimated to be 90 mg/day. This assumes that the maximum amount of soil ingested cannot be higher than the lowest estimate for the individual tracers.

Mean soil intake for the hospitalized children was estimated to be 56 mg/day based on aluminum (Table 5-3). For titanium, three of the children had estimates well in excess of 1,000 mg/day, with the remaining three children in the range of 28 to 58 mg/day. Using the LTM method, the mean soil ingestion rate was estimated to be 49 mg/day with a population standard deviation of 22 mg/day (range 26 to 84 mg/day). The geometric mean soil intake rate was 45 mg/day. The data on hospitalized children suggest a major nonsoil source of titanium for some children, and may suggest a background nonsoil source of aluminum. However, conditions specific to hospitalization (e.g., medications) were not considered. AIR measurements were not reported for the hospitalized children. Assuming that the tracer-based soil ingestion rates observed in hospitalized children actually represent background tracer intake from dietary and other nonsoil sources, mean soil ingestion by nursery school children was estimated to be 56 mg/day, based on the LTM (i.e., 105 mg/day for nursery school children minus 49 mg/day for hospitalized children) (Clausing et al. 1987).

The advantages of this study are that Clausing et al. (1987) evaluated soil ingestion among two populations of children that had differences in access to soil, and corrected soil intake rates based on background estimates derived from the hospitalized group. However, a smaller number of children were used in this study than in the Binder et al. (1986) study and these children may not be representative of the U.S. population. Tracer elements in foods or medicines were not evaluated. Also, intake rates derived from this study may not be representative of soil intake over the long-term because of the short-term nature of the study. In addition, one of the factors that could affect soil intake rates is hygiene (e.g., hand washing frequency). Hygienic practices can vary across countries and cultures and may be more stringently emphasized in a more structured environment such as child care centers in The Netherlands and other European countries than in child care centers in the United States.

Calabrese et al. (1989) - How Much Soil do Young Children Ingest: An Epidemiologic Study - Calabrese et al. (1989) studied soil ingestion among children using the basic tracer design developed by Binder et al. (1986). However, in contrast to the Binder et al. (1986) study, eight tracer elements (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) were analyzed instead of only three (i.e., aluminum, silicon, and titanium). A total of

64 children between the ages of 1 and 4 years old were included in the study. These children were all selected from the greater Amherst, Massachusetts area and were predominantly from two-parent households where the parents were highly educated. The Calabrese et al. (1989) study was conducted over eight days during a two week period and included the use of a mass-balance methodology in which duplicate samples of food, medicines, vitamins, and others were collected and analyzed on a daily basis, in addition to soil and dust samples collected from the child's home and play area. Fecal and urine samples were also collected and analyzed for tracer elements. Toothpaste, low in tracer content, was provided to all participants.

In order to validate the mass-balance methodology used to estimate soil ingestion rates among children and to determine which tracer elements provided the most reliable data on soil ingestion, known amounts of soil (i.e., 300 mg over three days and 1,500 mg over three days) containing eight tracers were administered to six adult volunteers (i.e., three males and three females). Soil samples and feces samples from these adults and duplicate food samples were analyzed for tracer elements to calculate recovery rates of tracer elements in soil. Based on the adult validation study, Calabrese et al. (1989) confirmed that the tracer methodology could adequately detect tracer elements in feces at levels expected to correspond with soil intake rates in children. Calabrese et al. (1989) also found that aluminum, silicon, and yttrium were the most reliable of the eight tracer elements analyzed. The standard deviation of recovery of these three tracers was the lowest and the percentage of recovery was closest to 100 percent (Calabrese, et al., 1989). The recovery of these three tracers ranged from 120 to 153 percent when 300 mg of soil had been ingested over a three-day period and from 88 to 94 percent when 1,500 mg soil had been ingested over a three-day period (Table 5-4).

Using the three most reliable tracer elements, the mean soil intake rate for children, adjusted to account for the amount of tracer found in food and medicines, was estimated to be 153 mg/day based on aluminum, 154 mg/day based on silicon, and 85 mg/day based on yttrium (Table 5-5). Median intake rates were somewhat lower (29 mg/day for aluminum, 40 mg/day for silicon, and 9 mg/day for yttrium). Upper-percentile (i.e., 95th) values were 223 mg/day for aluminum, 276 mg/day for silicon, and 106 mg/day for yttrium. Similar results were observed when soil and dust ingestion was combined (Table 5-5). Intake of soil and dust was estimated using a weighted ingestion for one child in the study ranged from approximately 10 to

14 grams/day during the second week of observation. Average soil ingestion for this child was 5 to 7 mg/day, based on the entire study period.

The advantages of this study are that intake rates were corrected for tracer concentrations in foods and medicines and that the methodology was validated using adults. Also, intake was observed over a longer time period in this study than in earlier studies and the number of tracers used was larger than for other studies. A relatively large population was studied, but they may not be entirely representative of the U.S. population because they were selected from a single location.

Davis et al. (1990) - Quantitative Estimates of Soil Ingestion in Normal Children Between the ages of 2 and 7 years: Population-Based Estimates Using Aluminum, Silicon, and Titanium as Soil Tracer Elements - Davis et al. (1990) also used a mass-balance/tracer technique to estimate soil ingestion among children. In this study, 104 children between the ages of 2 and 7 years were randomly selected from a three-city area in southeastern Washington State. The study was conducted over a seven day period, primarily during the summer. Daily soil ingestion was evaluated by collecting and analyzing soil and house dust samples, feces, urine, and duplicate food samples for aluminum, silicon, and titanium. In addition, information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil intake rates among children. The amount of soil ingested on a daily basis was estimated using the following equation:

$$S_{i.e} \quad \frac{(DW_f + DW_P)\ x\ E_f \quad 2E_u) \quad (DW_{fd}\ x\ E_{fd})}{E_{soil}} \qquad (5\text{-}2)$$

where:

$S_{i,e}$ = soil ingested for child i based on tracer e (g);
DW_f = feces dry weight (g);
DW_p = feces dry weight on toilet paper (g);
E_f = tracer amount in feces (μg/g);
E_u = tracer amount in urine (μg/g);
DW_{fd} = food dry weight (g);
E_{fd} = tracer amount in food (μg/g); and
E_{soil} = tracer concentration in soil (μg/g).

The soil intake rates were corrected by adding the amount of tracer in vitamins and medications to the amount of tracer in food, and adjusting the food quantities, feces dry weights, and tracer concentrations in urine to account for missing samples.

Soil ingestion rates were highly variable, especially those based on titanium. Mean daily soil ingestion estimates were 38.9 mg/day for aluminum, 82.4 mg/day for silicon and 245.5 mg/day for titanium (Table 5-6). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. Davis et al. (1990) also evaluated the extent to which differences in tracer concentrations in house dust and yard soil impacted estimated soil ingestion rates. The value used in the denominator of the mass balance equation was recalculated to represent a weighted average of the tracer concentration in yard soil and house dust based on the proportion of time the child spent indoors and outdoors. The adjusted mean soil/dust intake rates were 64.5 mg/day for aluminum, 160.0 mg/day for silicon, and 268.4 mg/day for titanium. Adjusted median soil/dust intake rates were: 51.8 mg/day for aluminum, 112.4 mg/day for silicon, and 116.6 mg/day for titanium. Davis et al. (1990) also observed that the following demographic characteristics were associated with high soil intake rates: male sex, non-white racial group, low income, operator/laborer as the principal occupation of the parent, and city of residence. However, none of these factors were predictive of soil intake rates when tested using multiple linear regression.

The advantages of the Davis et al. (1990) study are that soil intake rates were corrected based on the tracer content of foods and medicines and that a relatively large number of children were sampled. Also, demographic and behavioral information was collected for the survey group. However, although a relatively large sample population was surveyed, these children were all from a single area of the U.S. and may not be representative of the U.S. population as a whole. The study was conducted over a one-week period during the summer and may not be representative of long-term (i.e., annual) patterns of intake.

Van Wïjnen et al. (1990) - Estimated Soil Ingestion by Children - In a study by Van Wïjnen et al. (1990), soil ingestion among Dutch children ranging in age from 1 to 5 years was evaluated using a tracer element methodology similar to that used by Clausing et al. (1987). Van Wïjnen et al. (1990) measured three tracers (i.e., titanium, aluminum, and AIR) in soil and feces and estimated soil ingestion based on the LTM. An average daily feces weight of 15 g dry weight was assumed. A total of 292 children attending daycare centers were sampled during the first of two sampling periods and 187 children were sampled in the second sampling period; 162 of these children were sampled during both periods (i.e., at the beginning and near the end of the summer of 1986). A total of 78 children were sampled at campgrounds, and 15 hospitalized children were sampled. The mean values for these groups were: 162 mg/day for children in daycare centers, 213 mg/day for campers and 93 mg/day for hospitalized children. Van Wïjnen et al. (1990) also reported geometric mean LTM values because soil intake rates were found to be skewed and the log transformed data were approximately normally distributed. Geometric mean LTM values were estimated to be 111 mg/day for children in daycare centers, 174 mg/day for children vacationing at campgrounds (Table 5-7) and 74 mg/day for hospitalized children (70-120 mg/day based on the 95 percent confidence limits of the mean). AIR was the limiting tracer in about 80 percent of the samples. Among children attending daycare centers, soil intake was also found to be higher when the weather was good (i.e., <2 days/week precipitation) than when the weather was bad (i.e., >4 days/week precipitation (Table 5-8). Van Wïjnen et al. (1990) suggest that the mean LTM value for hospitalized infants represents background intake of tracers and should be used to correct the soil intake rates based on LTM values for other sampling groups. Using mean values, corrected soil intake rates were 69 mg/day (162 mg/day minus 93 mg/day) for daycare children and 120 mg/day (213 mg/day minus 93 mg/day) for campers. Corrected geometric mean soil intake was estimated to range from 0 to 90 mg/day with a 90th percentile value of 190 mg/day for the various age categories within the daycare group and 30 to 200 mg/day with a 90th percentile value of 300 mg/day for the various age categories within the camping group.

The advantage of this study is that soil intake was estimated for three different populations of children; one expected to have high intake, one expected to have "typical" intake, and one expected to have low or background-level intake. Van Wïjnen et al. (1990) used the background tracer measurements to correct soil intake rates for the other two populations. Tracer concentrations in food and medicine were not evaluated. Also, the population of children studied was relatively large, but may not be representative of the U.S. population. This study was conducted over a relatively short time period. Thus, estimated intake rates may not reflect long-term patterns, especially at the high-end of the distribution. Another limitation of this study is that values were not reported element-by-element which would be the preferred way of reporting. In addition, one of the factors that could affect soil intake rates is hygiene (e.g., hand washing frequency). Hygienic practices can vary across countries and cultures and may be more stringently emphasized in a more structured environment such as child care centers in The Netherlands and other European countries than in child care centers in the United States.

Stanek and Calabrese (1995a) - Daily Estimates of Soil Ingestion in Children - Stanek and Calabrese (1995a) presented a methodology which links the physical passage of food and fecal samples to construct daily soil ingestion estimates from daily food and fecal trace-element concentrations. Soil ingestion data for children obtained from the Amherst study (Calabrese et al., 1989) were reanalyzed by Stanek and Calabrese (1995a). In the Amherst study, soil ingestion measurements were made over a period of 2 weeks for a non-random sample of sixty-four children (ages of 1-4 years old) living adjacent to an academic area in western Massachusetts. During each week, duplicate food samples were collected for 3 consecutive days and fecal samples were collected for 4 consecutive days for each subject. The total amount of each of eight trace elements present in the food and fecal samples were measured. The eight trace elements are aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium. The authors expressed the amount of trace element in food input or fecal output as a "soil equivalent," which was defined as the amount of the element in average daily food intake (or average daily fecal output) divided by the concentration of the element in soil. A lag period of 28 hours between food intake and fecal output was assumed for all respondents. Day 1 for the food sample corresponded to the 24 hour period from midnight on Sunday to midnight on Monday of a study week; day 1 of the fecal sample corresponded to the 24 hour period from noon on Monday to noon on Tuesday (Stanek and Calabrese, 1995a). Based on these definitions, the food soil equivalent was subtracted from the fecal soil equivalent to obtain an estimate of soil ingestion for a trace element. A daily “overall” ingestion estimate was constructed for each child as the median of trace element values remaining after tracers falling outside of a defined range around the overall median were excluded. Additionally, estimates of the distribution of soil ingestion projected over a period of 365 days were derived by fitting log-normal distributions to the “overall” daily soil ingestion estimates.

Table 5-9 presents the estimates of mean daily soil ingestion intake per child (mg/day) for the 64 study participants. (The authors also presented estimates of the median values of daily intake for each child. For most risk assessment purposes the child mean values, which are proportional to the cumulative soil intake by the child, are needed instead of the median values.)

The approach adopted in this paper led to changes in ingestion estimates from those presented in Calabrese et al. (1989).

Specifically, among elements that may be more useful for estimation of ingestion, the mean estimates decreased for Al (153 mg/d to 122 mg/d) and Si (154 mg/d to 139 mg/d), but increased for Ti (218 mg/d to 271 mg/d) and Y (85 mg/d to 165 mg/d). The "overall" mean estimate from this reanalysis was 179 mg/d. Table 5-9 presents the empirical distribution of the the "overall" mean daily soil ingestion estimates for the 8-day study period (not based on lognormal modeling). The estimated intake based on the "overall" estimates is 45 mg/day or less for 50 percent of the children and 208 mg/day or less for 95 percent of the children. The upper percentile values for most of the individual trace elements are somewhat higher. Next, estimates of the respondents soil intake averaged over a period of 365 days were presented based upon the lognormal models fit to the daily ingestion estimates (Table 5-10). The estimated median value of the 64 respondents' daily soil ingestion averaged over a year is 75 mg/day, while the 95th percentile is 1,751 mg/day.

A strength of this study is that it attempts to make full use of the collected data through estimation of daily ingestion rates for children. The data are then screened to remove less consistent tracer estimates and the remaining values are aggregated. Individual daily estimates of ingestion will be subject to larger errors than are weekly average values, particularly since the assumption of a constant lag time between food intake and fecal output may be not be correct for many subject days. The aggregation approach used to arrive at the "overall" ingestion estimates rests on the assumption that the mean ingestion estimates across acceptable tracers provides the most reliable ingestion estimates. The validity of this assumption depends on the particular set of tracers used in the study, and is not fully assessed.

In developing the 365 day soil ingestion estimates, data that were obtained over a short period of time (as is the case with all available soil ingestion studies) were extrapolated over a year. The 2-week study period may not reflect variability in tracer element ingestion over a year. While Stanek and Calabrese (1995a) attempt to address this through lognormal modeling of the long term intake, new uncertainties are introduced through the parametric modeling of the limited subject day data. Also, the sample population size of the original study was small and site limited, and, therefore, is not representative of the U.S. population. Study mean estimates of soil ingestion, such as the study mean estimates presented in Table 5-9, are substantially more reliable than any available distributional estimates.

Stanek and Calabrese (1995b) - Soil Ingestion Estimates for Use in Site Evaluations Based on the Best Tracer Method - Stanek and Calabrese (1995b) recalculated ingestion rates that were estimated in three previous mass-balance studies (Calabrese et al., 1989 and Davis et al., 1990 for children's soil ingestion, and Calabrese et al., 1990 for adult soil ingestion) using the Best Tracer Method (BTM). This method allows for the selection of the most recoverable tracer for a particular subject or group of subjects. The selection process involves ordering trace elements for each subject based on food/soil (F/S) ratios. These ratios are estimated by dividing the total amount of the tracer in food by the tracer concentration in soil. The F/S ratio is small when the tracer concentration in food is almost zero when compared to the tracer concentration in soil. A small F/S ratio is desirable because it lessens the impact of transit time error (the error that occurs when fecal output does not reflect food ingestion, due to fluctuation in gastrointestinal transit time) in the soil ingestion calculation. Because the recoverability of tracers can vary within any group of individuals, the BTM uses a ranking scheme of F/S ratios to determine the best tracers for use in the ingestion rate calculation. To reduce biases that may occur as a result of sources of fecal tracers other than food or soil, the median of soil ingestion estimates based on the four lowest F/S ratios was used to represent soil ingestion among individuals.

For children, Stanek and Calabrese (1995b) used data on 8 tracers from Calabrese et al., 1989 and data on 3 tracers from Davis et al. (1990) to estimate soil ingestion rates. The median of the soil ingestion estimates from the lowest four F/S ratios from the Calabrese et al. (1989) study most often included Al, Si, Ti, Y, and Zr. Based on the median of soil ingestion estimates from the best four tracers, the mean soil ingestion rate was 132 mg/day and the median was 33 mg/day. The 95th percentile value was 154 mg/day. These estimates are based on data for 128 subject weeks for the 64 children in the Calabrese et al. (1989) study. For the 101 children in the Davis et al. (1990) study, the mean soil ingestion rate was 69 mg/day and the median soil ingestion rate was 44 mg/day. The 95th percentile estimate was 246 mg/day. These data are based on the three tracers (i.e., Al, Si, and Ti) from the Davis et al. (1990) study. When the Calabrese et al. (1989) and Davis et al. (1990) studies were combined, soil ingestion was estimated to be 113 mg/day (mean); 37 mg/day (median); and 217 mg/day (95th percentile), using the BTM.

This study provides a reevaluation of previous studies. Its advantages are that it combines data from 2 studies for children, one from California and one from Massachusetts, which increases the number of observations. It also corrects for biases associated with the differences in tracer metabolism. The limitations associated with the data used in this study are the same as the limitations described in the summaries of the Calabrese et al. (1989), Davis et al. (1990) and Calabrese et al. (1990) studies.

Thompson and Burmaster (1991) - Parametric Distributions for Soil Ingestion by Children - Thompson and Burmaster (1991) developed parameterized distributions of soil ingestion rates for children based on a reanalysis of the key study data collected by Binder et al. (1986). In the original Binder et al. (1986) study, an assumed fecal weight of 15 g/day was used. Thompson and Burmaster reestimated the soil ingestion rates from the Binder et al. (1986) study using the actual stool weights of the study participants instead of the assumed stool weights. Because the actual stool weights averaged only 7.5 g/day, the soil ingestion estimates presented by Thompson and Burmaster (1991) are approximately one-half of those reported by Binder et al. (1986). Table 5-11 presents the distribution of estimated soil ingestion rates calculated by Thompson and Burmaster (1991) based on the three tracers elements (i.e., aluminum, silicon, and titanium), and on the arithmetic average of soil ingestion based on aluminum and silicon. The mean soil intake rates were 97 mg/day for aluminum, 85 mg/day for silicon, and 1,004 mg/day for titanium. The 90th percentile estimates were 197 mg/day for aluminum, 166 mg/day for silicon, and 2,105 mg/day for titanium. Based on the arithmetic average of aluminum and silicon for each child, mean soil intake was estimated to be 91 mg/day and 90th percentile intake was estimated to be 143 mg/day.

Thompson and Burmaster (1991) tested the hypothesis that soil ingestion rates based on the adjusted Binder et al. (1986) data for aluminum, silicon and the average of these two tracers were lognormally distributed. The distribution of soil intake based on titanium was not tested for lognormality because titanium may be present in food in high concentrations and the Binder et al. (1986) study did not correct for food sources of titanium (Thompson and Burmaster, 1991). Although visual inspection of the distributions for aluminum, silicon, and the average of these tracers all indicated that they may be lognormally distributed, statistical tests indicated that only silicon and the average of the silicon and aluminum tracers were lognormally distributed. Soil intake rates based on aluminum were not lognormally distributed. Table 5-11 also presents the lognormal distribution parameters and underlying normal distribution parameters (i.e., the natural logarithms of the data) for aluminum, silicon, and the average of these two tracers. According to the authors, "the parameters estimated from the underlying normal distribution are much more reliable and robust" (Thompson and Burmaster, 1991).

The advantages of this study are that it provides percentile data and defines the shape of soil intake distributions. However, the number of data points used to fit the distribution was limited. In addition, the study did not generate "new" data. Instead, it provided a reanalysis of previously-reported data using actual fecal weights. No corrections were made for tracer intake from food or medicine and the results may not be representative of long-term intake rates because the data were derived from a short-term study.

Sedman and Mahmood (1994) - Soil Ingestion by Children and Adults Reconsidered Using the Results of Recent Tracer Studies - Sedman and Mahmood (1994) used the results of two of the key children’s tracer studies (Calabrese et al. 1989; Davis et al. 1990) to determine estimates of average daily soil ingestion in young children and for over a lifetime. In the two studies, the intake and excretion of a variety of tracers were monitored, and concentrations of tracers in soil adjacent to the children’s dwellings were determined (Sedman and Mahmood, 1994). From a mass balance approach, estimates of soil ingestion in these children were determined by dividing the excess tracer intake (i.e., quantity of tracer recovered in the feces in excess of the measured intake) by the average concentration of tracer in soil samples from each child's dwelling. Sedman and Mahmood (1994) adjusted the mean estimates of soil ingestion in children for each tracer (Y) from both studies to reflect that of a 2-year old child using the following equation:

$$Y_i = xe^{(-0.112*yr)} \tag{5-3}$$

where:

Y_i = adjusted mean soil ingestion (mg/day)
x = a constant
yr = average age (2 years)

The average ages of children in the two key studies were 2.4 years in Calabrese et al. (1989) and 4.7 years in Davis et al. (1990). The mean of the adjusted levels of soil ingestion for a two year old child was 220 mg/kg for the Calabrese et al. (1989) study and 170 mg/kg for the Davis et al. (1990) study (Sedman and Mahmood, 1994). From the adjusted soil ingestion estimates, based on a normal distribution of means, the mean estimate for a 2-year old child was 195 mg/day and the overall mean of soil ingestion and the standard error of the mean was 53 mg/day (Sedman and Mahmood, 1994). Based on uncertainties associated with the method employed, Sedman and Mahmood (1994) recommended a conservative estimate of soil ingestion in young children of 250 mg/day. Based on the 250 mg/day ingestion rate in a 2-year old child, an average daily soil ingestion over a lifetime was estimated to be 70 mg/day. The lifetime estimates were derived using the equation presented above that describes changes in soil ingestion with age (Sedman and Mahmood, 1994).

Calabrese and Stanek (1995) - Resolving Intertracer Inconsistencies in Soil Ingestion Estimation - Calabrese and Stanek (1995) explored sources and magnitude of positive and negative errors in soil ingestion estimates for children on a subject-week and trace element basis. Calabrese and Stanek (1995) identified possible sources of positive errors to be the following:

- Ingestion of high levels of tracers before the study starts and low ingestion during study period may result in over estimation of soil ingestion; and
- Ingestion of element tracers from a non-food or non-soil source during the study period.

Possible sources of negative bias identified by Calabrese and Stanek (1995) are the following:

- Ingestion of tracers in food, but the tracers are not captured in the fecal sample either due to slow lag time or not having a fecal sample available on the final study day; and
- Sample measurement errors which result in diminished detection of fecal tracers, but not in soil tracer levels.

The authors developed an approach which attempted to reduce the magnitude of error in the individual trace element ingestion estimates. Results from a previous study conducted by Calabrese et al. (1989) were used to quantify these errors based on the following criteria: (1) a lag period of 28 hours was assumed for the passage of tracers ingested in food to the feces (this value was applied to all subject-day estimates); (2) daily soil ingestion rate was estimated for each tracer for each 24-hr day a fecal sample was obtained; (3) the median tracer-based soil ingestion rate for each subject-day was determined. Also, upper and lower bound estimates were determined based on criteria formed using an assumption of the magnitude of the relative standard deviation (RSD) presented in another study conducted by Stanek and Calabrese (1995a). Daily soil ingestion rates for tracers that fell beyond the upper and lower ranges were excluded from subsequent calculations, and the median soil ingestion rates of the remaining tracer elements were considered the best estimate for that particular day. The magnitude of positive or negative error for a specific tracer per day was derived by determining the difference between the value for the tracer and the median value; (4) negative errors due to missing fecal samples at the end of the study period were also determined (Calabrese and Stanek, 1995).

Table 5-12 presents the estimated magnitude of positive and negative error for six tracer elements in the children's study (i.e., conducted by Calabrese et al., 1989). The original mean soil ingestion rates ranged from a low of 21 mg/day based on zirconium to a high of 459 mg/day based on titanium (Table 5-12). The adjusted mean soil ingestion rate after correcting for negative and positive errors ranged from 97 mg/day based on yttrium to 208 mg/day based on titanium (Table 5-12). Calabrese and Stanek (1995) concluded that correcting for errors at the individual level for each tracer element provides more reliable estimates of soil ingestion.

This report is valuable in providing additional understanding of the nature of potential errors in trace element specific estimates of soil ingestion. However, the operational definition used for estimating the error in a trace element estimate was the observed difference of that tracer from a median tracer value. Specific identification of sources of error, or direct evidence that individual tracers were indeed in error was not developed. Corrections to individual tracer means were then made according to how different values for that tracer were from the median values. This approach is based on the hypothesis that the median tracer value is the most accurate estimate of soil ingestion, and the validity of this assumption depends on the specific set of tracers used in the study and need not be correct. The approach used for the estimation of daily tracer intake is the same as in Stanek and Calabrese (1995a), and some limitations of that approach are mentioned in the review of that study.

Calabrese et al. (1997) – Soil Ingestion for Children Residing on a Superfund Site - Calabrese et al. (1997) estimated soil ingestion rates for children residing on a Superfund site using a mass-balance methodology in which eight tracer elements (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) were analyzed. The methodology used in this study is very similar to the one conducted in Calabrese et al. (1989). As in Calabrese et al. (1989), 64 children ages 1-4 years were selected for this study and were predominantly from two-parent households. This stratified simple random sample of children was selected from the Anoconda, Montana area. Thirty-six of the 64 children were male, and the children ranged in age from 1 to 3 years with approximately an equal number of children in each age group. The Calabrese et al. (1997) study was conducted for seven consecutive days during a two week period in the month of September. Duplicate samples of meals, beverages, and over-the-counter medicines and vitamins were collected over the seven day period, along with fecal samples. In addition, soil and dust samples were collected from the children's home and play areas. Toothpaste containing nondetectable levels of the tracer elements, with the exception of silica, was provided to all of the children. Infants were provided with baby cornstarch, diaper rash cream, and soap which were found to contain low levels of tracer elements.

As in Calabrese et al. (1989), an additional study was conducted in which the identical mass-balance methodology used to estimate soil ingestion rates among children was used on adults in order to validate that soil ingestion could be detected. Known amounts of soil were administered to ten adults (5 males, 5 females) from Western Massachusetts over a period of 28 days. Each adult ingested for 7 consecutive days 1) no soil during Week 1, 2) 20 mg of sterilized soil during Week 2, 3) 100 mg of sterilized soil during Week 3, and 4) 500 mg of sterilized soil during Week 4. Soil samples were previously characterized and were of sufficient concentration to be detected in the analysis of fecal samples. Duplicate food and fecal samples were collected every day during each study week and analyzed for the eight tracer elements (Al, Si, Ti, Ce, La, Nd, Y, and Zr). It was found that ingestion of soil from 20 to 500 mg/day could be detected in a reliable manner.

Calabrese et al. (1997) estimated soil ingestion by each tracer element using the Best Tracer Method (BTM) which allows for the selection of the most recoverable tracer for a particular group of subjects (Stanek and Calabrese, 1995b). In this case BA, Mn, and V were dropped as they were found to be poor performing tracers. The median soil ingestion estimates for the four best trace elements based on Food/Soil ratios for the 64 children using Al, Si, Ti, Y, and Zr were presented (Table 5-13). Based on the soil ingestion estimate for the best tracer, the mean soil ingestion rate was 66 mg/day and the median was 20 mg/day. The 95th percentile value was 280 mg/day. Using the median of the 4 best tracers, the mean was 7 mg/day and the 95th percentile was 160 mg/day. These results are lower than the soil ingestion estimates obtained by Stanek and Calabrese (1995a). Calabrese et al. (1997) believe this may be due to the fact that the families of the children who participated in this study were aware that they lived on an EPA Superfund site and this knowledge might have resulted in reduced exposure. There was no statistically significant difference found in soil ingestion estimates by gender or age. There was also no significant difference in soil ingestion by housing or yard characteristics (i.e., porch, deck, door mat, etc.), or between children with or without pets.

The median dust ingestion estimates for the four best tracer elements using Al, Si, Ti, Y, and Zr were also presented (Table 5-14). The mean dust ingestion rate based on the best tracer was 130 mg/day and the 95th percentile rate was 614 mg/day.

The advantages of this study were the use of a longer 7 consecutive day study period rather than two periods of 3 and 4 days (Stanek and Calabrese, 1995a), the use of the BTM, the use of an expanded adult validation study which used 10 volunteers rather than 6 (Calabrese et al., 1989), and the use of a dietary education program to reduce food tracer input and variability. However, the data presented in this study are from a single 7-day period during September which may not reflect soil ingestion rates for other months or time-periods. In addition, the study displayed a net residual negative error, which may have resulted in underestimated soil ingestion rates. Calabrese et al. (1997) believe that this error is not likely to affect the median by more than 40 mg/day.

5.3 PREVALENCE OF PICA

The scientific literature define pica as "the repeated eating of non-nutritive substances" (Feldman, 1986). For the purposes of this handbook, pica is defined as an deliberately high <u>soil</u> ingestion rate. Numerous articles have been published that report on the incidence of pica among various populations. However, most of these papers describe pica for substances other than soil including sand, clay, paint, plaster, hair, string, cloth, glass, matches, paper, feces, and various other items. These papers indicate that the pica occurs in approximately half of all children between the ages of 1 and 3 years (Sayetta, 1986). The incidence of deliberate ingestion behavior in children has been shown to differ for different subpopulations. The incidence rate appears to be higher for black children than for white children. Approximately 30 percent of black children aged 1 to 6 years are reported to have deliberate ingestion behavior, compared with 10 to 18 percent of white children in the same age group (Danford, 1982). There does not appear to be any sex differences in the incidence rates for males or females (Kaplan and Sadock, 1985). Lourie et al. (1963) states that the incidence of pica is higher among children in lower socioeconomic groups (i.e., 50 to 60 percent) than in higher income families (i.e., about 30 percent). Deliberate soil ingestion behavior appears to be more common in rural areas (Vermeer and Frate, 1979). A higher rate of pica has also been reported for pregnant women and individuals with poor nutritional status (Danford, 1982). In general, deliberate ingestion behavior is more frequent and more severe in mentally retarded children than in children in the general population (Behrman and Vaughan 1983, Danford 1982, Forfar and Arneil 1984, Illingworth 1983, Sayetta 1986).

It should be noted that the pica statistics cited above apply to the incidence of general pica and not soil pica. Information on the incidence of soil pica is limited, but it appears that soil pica is less common. A study by Vermeer and Frate (1979) showed that the incidence of geophagia (i.e., earth-eating) was about 16 percent among children from a rural black community in Mississippi. However, geophagia was described as a cultural practice among the community surveyed and may not be representative of the general population. Average daily consumption of soil was estimated to be 50 g/day. Bruhn and Pangborn (1971) reported the incidence of pica for "dirt" to be 19 percent in children, 14 percent in pregnant women, and 3 percent in nonpregnant women. However, "dirt" was not clearly defined. The Bruhn and Pangborn (1971) study was conducted among 91 non-black, low income families of migrant agricultural workers in California. Based on the data from the five key tracer studies (Binder et al., 1986; Clausing et al., 1987; Van Wïjnen et al., 1990; Davis et al., 1990; and Calabrese et al., 1989) only one child out of the more than 600 children involved in all of these studies ingested an amount of soil significantly greater than the range for other children. Although these studies did not include data for all populations and were representative of short-term ingestions only, it can be assumed that the incidence rate of deliberate soil ingestion behavior in the general population is low. However, it is incumbent upon the user to use the appropriate value for their specific study population.

5.4 DELIBERATE SOIL INGESTION AMONG CHILDREN

Information on the amount of soil ingested by children with abnormal soil ingestion behavior is limited. However, some evidence suggests that a rate on the order of 10 g/day may not be unreasonable.

Calabrese et al. (1991) - Evidence of Soil Pica Behavior and Quantification of Soil Ingestion - Calabrese et al. (1991) estimated that upper range soil ingestion values may range from approximately 5-7 grams/day. This estimate was based on observations of one pica child among the 64 children who participated in the study. In the study, a 3.5-year old female exhibited extremely high soil ingestion behavior during one of the two weeks of observation. Intake ranged from 74 mg/day to 2.2 g/day during the first week of observation and 10.1 to 13.6 g/day during the second week of observation (Table 5-15). These results are based on mass-balance analyses for seven (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, and yttrium) of the eight tracer elements used. Intake rates based on zirconium was significantly lower but Calabrese et al. (1991) indicated that this may have "resulted from a limitation in the analytical protocol."

Calabrese and Stanek (1992) - Distinguishing Outdoor Soil Ingestion from Indoor Dust Ingestion in a Soil Pica Child - Calabrese and Stanek (1992) quantitatively distinguished the amount of outdoor soil ingestion from indoor dust ingestion in a soil pica child. This study was based on a previous mass-balance study (conducted in 1991) in which a 3-1/2 year old child ingested 10-13 grams of soil per day over the second week of a 2-week soil ingestion study. Also, the previous study utilized a soil tracer methodology with eight different tracers (Al, Ba, Mn, Si, Ti, V, Y, Zr). The reader is referred to Calabrese et al. (1989) for a detailed description and results of the soil ingestion study. Calabrese and Stanek (1992) distinguished indoor dust from outdoor soil in ingested soil based on a methodology which compared differential element ratios.

Table 5-16 presents tracer ratios of soil, dust, and residual fecal samples in the soil pica child. Calabrese and Stanek (1992) reported that there was a maximum total of 28 pairs of tracer ratios based on eight tracers. However, only 19 pairs of tracer ratios were available for quantitative evaluation as shown in Table 5-16. Of these 19 pairs, 9 fecal tracer ratios fell within the boundaries for soil and dust (Table 5-16). For these 9 tracer soils, an interpolation was performed to estimate the relative contribution of soil and dust to the residual fecal tracer ratio. The other 10 fecal tracer ratios that fell outside the soil and dust boundaries were concluded to be 100 percent of the fecal tracer ratios from soil origin (Calabrese and Stanek, 1992). Also, the

9 residual fecal samples within the boundaries revealed that a high percentage (71-99 percent) of the residual fecal tracers were estimated to be of soil origin. Therefore, Calabrese and Stanek (1992) concluded that the predominant proportion of the fecal tracers was from outdoor soil and not from indoor dust origin.

In conducting a risk assessment for TCDD, U.S. EPA (1984) used 5 g/day to represent the soil intake rate for pica children. The Centers for Disease Control (CDC) also investigated the potential for exposure to TCDD through the soil ingestion route. CDC used a value of 10 g/day to represent the amount of soil that a child with deliberate soil ingestion behavior might ingest (Kimbrough et al., 1984). These values are consistent with those observed by Calabrese et al. (1991).

Calabrese, E. J. and E. J. Stanek (1993) - Soil Pica: Not a Rare Event - Calabrese and Stanek critiqued a study by Wong (1988) that attempted to estimate the amount of soil ingested by two groups of children. Wong (1988) studied a total of 52 children who were in two separate government institutions in Jamaica. The children had an average age of 3.1 years (ranging from 0.3 to 7.6 years) and 7.2 years (ranging from 1.8 to 14 years). The younger group (from the Glenhope Place of Safety) contained 24 children and the older group (from the Reddies Place of Safety) had 28 children. Fecal samples were obtained from the subject children and the amount of silicon, a soil tracer, in dry feces was measured in order to quantify soil ingestion.

Using a hospital control group of 30 children with an average age of 4.8 years (ranging from 0.3 to 12 years), the authors of the study collected an unspecified number of daily fecal samples. Based on these samples, dry feces were observed as containing 1.45 percent silicon or 14.5 mg of silicon per 1 g of dry feces. The authors assumed that this amount of silicon in dry feces was representative of the typical background amount of silicon from dietary sources only. Observed quantities of silicon greater than 1.45 percent were then assumed to be from soil ingestion.

Wong (1988) calculated the amount of soil ingested by using the standard soil ingestion estimation formula (Binder et al. 1986). One fecal sample was collected from each subject per month over the four month study period.

For the 28 children in the older group (average age 7.2 years), soil ingestion was estimated to be 58 mg/day based on the mean minus one outlier and 1,520 mg/day based on the mean of all the children. The group contained one outlier, a child with an estimated average soil ingestion rate of 41 g/day over the four months. Some of the observed soil ingestion results for this group of children included:

- 7 of 28 had average soil ingestion of >100 mg/day,
- 4 of 28 had average soil ingestion of >200 mg/day,
- 1 of 28 had average soil ingestion of >300 mg/day, and
- 8 of 28 showed no indication of soil ingestion for any month.

Estimated average soil ingestion in the younger group of children (average age 3.1 years) was higher. The mean soil ingestion of all the children was 470 ± 370 mg/day. Due to some sample losses, of the 24 children studied, only 15 subjects had samples for each of the four months. Observed soil ingestion estimates for this group included:

- 14 of 24 had average soil ingestion of <100 mg/day,
- 10 of 24 had average soil ingestion of >100 mg/day,
- 5 of 24 had average soil ingestion of >600 mg/day,
- 4 of 24 had average soil ingestion of >1,000 mg/day, and
- 5 of 24 showed no indication of soil ingestion for any month.

Over the entire 4 month study duration, 9 of 84 total samples (or 10.5%) showed soil ingestion estimates of >1 g/day (pica behavior). Of the 52 children studied by Wong (1988), six children displayed soil pica behavior. The estimated soil ingestion for each of these subjects is shown in Table 5-17. For the younger group of children (Glenhope Place of Safety), 5 of 24 (or 20.8%) displayed soil pica behavior on at least one occasion. A high degree of daily variability in soil ingestion was observed among the 6 children exhibiting pica behavior. As shown in Table 5-17, 3 of 6 children (#11, 12, and 22) showed soil pica on only 1 of 4 days. The other 3 children (#14, 18, and 27) ingested ≥1.0 g/d on 2 of 4, on 3 of 4, and 4 of 4 days, respectively. Subject #27 displayed a high degree of soil pica, ranging from 3.7 to 60.6 g/d of soil ingestion; however, it was indicated that this child was mentally retarded while the other pica children were considered to have normal mental capabilities.

Sources of uncertainty or error in this study include differences between the hospital (i.e., control) study group (the background control) and the 2 study groups; lack of information on the dietary intake of silicon for the studied children; use of a single fecal sample; and loss of fecal samples. The use of a single soil tracer may also introduce error since there may be other sources from which the tracer could originate. For example, some toothpastes have extremely high concentrations of silicon and children could ingest significant quantities of toothpaste. Additionally, tracers could be found in indoor dust that children may ingest. However, given these uncertainties, the results are important in that they indicate that soil pica is not a rare occurrence in younger children.

Stanek et al. (1998) - Prevalence of Soil Mouthing/Ingestion among Healthy Children Aged 1 to 6 - Stanek et al. (1998) presented a methodology that links mouthing behavior among children to the prevalence of ingestion of non-food items. Soil ingestion data were collected via face-to-face interviews over a period of 3 months from parents or guardians of 533 children ages 1 to 6 years old attending well-visits in Western Massachusetts. Three clinics participated in this study during the months of August, September, and October, 1992: Kaiser Permanente's clinic in Amherst, a private clinic associated with the Cooley Dickinson Hospital in Northampton, and the BayState Medical Center clinic in Springfield. Stanek et al. (1998) questioned the participants about the frequency of 28 mouthing behaviors of the children over the past month in addition to exposure time (e.g., time outdoors, play in sand or dirt) and children's characteristics (e.g., teething). Response categories of the clinic questionnaire corresponded to daily, at least weekly, at least monthly, and never. Stanek et al. (1998) expressed the mouthing rate for each child as the sum of rates for responses to four questions on mouthing specific outdoor objects. Regression models with variables in a step-wise manner identified factors related to high outdoor mouthing rates. Stanek et al. (1998) first considered variables that indicated opportunity for exposure, then subjects' characteristics (e.g., teething) and environmental factors, and finally, concurrent reported behaviors.

Table 5-18 presents the prevalence of non-ingestion/mouthing behaviors by child's age as the percent of children whose parents reported the behavior in the past month. Stanek et al. (1998) found that outdoor soil mouthing behavior prevalence was higher than indoor dust mouthing prevalence, but both behaviors had highest prevalence among 1-year-old children, and dropped quickly among children 2 years old and older. Stanek et al. (1998) conducted principal component analyses on response to four questions relating to ingestion of outdoor objects (Table 5-18) in an attempt to characterize variability. Responses were converted to mouthing rates per week, using values of 0, 0.25, 1, and 7 for responses of never, monthly, weekly, and daily ingestion. Stanek et al. (1998) found outdoor ingestion/mouthing rates for children 1 years of age to be 4.73 per week and 0.44 per week for children 2-6 years of age. Stanek et al. (1998) estimated the frequency of children playing in sand/dirt as a measure of potential exposure, and found that 71 percent of the children were reported to play in sand or dirt at least weekly, and 45 percent were reported as playing in the sand or dirt daily. The authors found that children who played in the sand or dirt had higher outdoor object ingestion/mouthing rates. Thus, children with higher direct exposure to sand or dirt were more likely to ingest or mouth on outdoor objects. Stanek et al. (1998) found similar results when comparing the time spent outdoors to reported outdoor ingestion and mouthing rates. Sixty-five percent of one-year old children were reported to spend less than 3 hour per day outdoors, while 42 percent of children 2-6 years old spend less than 3 hours per day outdoors.

Table 5-19 presents average outdoor mouthing rates by age and sand/dirt play frequency. Stanek et al. (1998) presented the data for children by quartiles according to their general mouthing rates and applied linear regression models fit to general mouthing rates. The authors found a significant slope for all groups but one, and thus demonstrated that outdoor mouthing behavior increased with higher quartiles and that rates of increase depended on age and sand/soil play exposure.

A strength of this study is that it focuses on the prevalence of specific behaviors to quantify soil mouthing or ingestion among healthy children. The results of this study might have important health implications as it showed that one-year-old children with high general levels of mouthing behavior have the potential for high risk soil ingestion.

A limitation associated with this study is that the data are based on recall behavior from the summer previous to the interview. Extrapolation to other seasons may be difficult. In addition, data were collected for children in Western Massachusetts and data were only available for the healthy children who were present for well-visits.

5.5 RECOMMENDATIONS

The studies described in this section were used to recommend values for soil intake among children. Estimates of the amount of soil ingested by children are summarized in Table 5-20 and the recommended values are presented in Table 5-21. The mean values ranged from 39 mg/day to 271 mg/day with an average of 138 mg/day for soil ingestion and 193 mg/day for soil and dust ingestion. Results obtained using titanium as a tracer in the Binder et al. (1986) and Clausing et al. (1987) studies were not considered in the derivation of this recommendation because these studies did not take into consideration other sources of the element in the diet which for titanium seems to be significant. Therefore, these values may overestimate the soil intake. One can note that this group of mean values is consistent with the 200 mg/day value that EPA programs have used as a conservative mean estimate. Taking into consideration that the highest values were seen with titanium, which may exhibit greater variability than the other tracers, and the fact that the Calabrese et al. (1989) study included a pica child, 100 mg/day is the best estimate of the mean for children under 6 years of age. However, since the children were studied for short periods of time and the prevalence of pica behavior is not known, excluding the pica child from the calculations may underestimate soil intake rates. It is plausible that many children may exhibit some pica behavior if studied for longer periods of time. Over the period of study, upper percentile values ranged from 106 mg/day to 1,432 mg/day with an average of 358 mg/day for soil ingestion and 790 mg/day for soil and dust ingestion. Rounding to one significant figure, the recommended upper percentile soil ingestion rate for children is 400 mg/day. However, since the period of study was short, these values are not estimates of usual intake.

Data on soil ingestion rates for children who deliberately ingest soil are also limited. An ingestion rate of 10 g/day is a reasonable value for use in acute exposure assessments, based on the available information. It should be noted, however, that this value is based on only one pica child observed in the Calabrese et al. (1989) study.

It should be noted that these recommendations are based on studies that used different survey designs and populations. For example, some of the studies considered food and nonfood sources of trace elements, while others did not. In other studies, soil ingestion estimates were adjusted to account for the contribution of house dust to this estimate. Despite these differences, the mean and upper-percentile estimates reported for these studies are relatively consistent. The confidence rating for soil intake recommendations is presented in Table 5-22. It is important, however, to understand the various uncertainties associated with these values. First, individuals were not studied for sufficient periods of time to get a good estimate of the usual intake. Therefore, the values presented in this section may not be representative of long term exposures. Second, the experimental error in measuring soil ingestion values for individual children is also a source of uncertainty. For example, incomplete sample collection of both input (i.e., food and nonfood sources) and output (i.e., urine and feces) is a limitation for some of the studies conducted. In addition, an individual's soil ingestion value may be artificially high or low depending on the extent to which a mismatch between input and output occurs due to individual variation in the gastrointestinal transit time. Third, the degree to which the tracer elements used in these studies are absorbed in the human body is uncertain. Accuracy of the soil ingestion estimates depends on how good this assumption is. Fourth, there is uncertainty with regard to the homogeneity of soil samples and the accuracy of parent's knowledge about their child's playing areas. Fifth, all the soil ingestion studies presented in this section with the exception of Calabrese et al. (1989) were conducted during the summer when soil contact is more likely.

Although the recommendations presented below are derived from studies which were mostly conducted in the summer, exposure during the winter months when the ground is frozen or snow covered should not be considered as zero. Exposure during these months, although lower than in the summer months, would not be zero because some portion of the house dust comes from outdoor soil.

5.6 REFERENCES FOR CHAPTER 5

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Table 5-1. Estimated Daily Soil Ingestion Based on Aluminum, Silicon, and Titanium Concentrations

Estimation Method	Mean (mg/day)	Median (mg/day)	Standard Deviation (mg/day)	Range (mg/day)	95th Percentile (mg/day)	Geometric Mean (mg/day)
Aluminum	181	121	203	25-1,324	584	128
Silicon	184	136	175	31-799	5,78	130
Titanium	1,834	618	3,091	4-17,076	9,590	401
Minimum	108	88	121	4-708	386	65

Source: Binder et al. (1986).

Table 5-2. Calculated Soil Ingestion by Nursery School Children

Child	Sample Number	Soil Ingestion as Calculated from Ti (mg/day)	Soil Ingestion as Calculated from Al (mg/day)	Soil Ingestion as Calculated from AIR (mg/day)	Limiting Tracer (mg/day)
1	L3	103	300	107	103
	L14	154	211	172	154
	L25	130	23	-	23
2	L5	131	-	71	71
	L13	184	103	82	82
	L27	142	81	84	81
3	L2	124	42	84	42
	L17	670	566	174	174
4	L4	246	62	145	62
	L11	2,990	65	139	65
5	L8	293	-	108	108
	L21	313	-	152	152
6	L12	1,110	693	362	362
	L16	176	-	145	145
7	L18	11,620	-	120	120
	L22	11,320	77	-	77
8	L1	3,060	82	96	82
9	L6	624	979	111	111
10	L7	600	200	124	124
11	L9	133	-	95	95
12	L10	354	195	106	106
13	L15	2,400	-	48	48
14	L19	124	71	93	71
15	L20	269	212	274	212
16	L23	1,130	51	84	51
17	L24	64	566	-	64
18	L26	184	56	-	56
Arithmetic Mean		1,431	232	129	105

Source: Adapted from Clausing et al. (1987).

Table 5-3. Calculated Soil Ingestion by Hospitalized, Bedridden Children

Child	Sample	Soil Ingestion as Calculated from Ti (mg/day)	Soil Ingestion as Calculated from Al (mg/day)	Limiting Tracer (mg/day)
1	G5	3,290	57	57
	G6	4,790	71	71
2	G1	28	26	26
3	G2	6,570	94	84
	G8	2,480	57	57
4	G3	28	77	28
5	G4	1,100	30	30
6	G7	58	38	38
Arithmetic Mean		2,293	56	49

Source: Adapted from Clausing et al. (1987).

Table 5-4. Mean and Standard Deviation Percentage Recovery of Eight Tracer Elements

Tracer Element	300 mg Soil Ingested		1,500 mg Soil Ingested	
	Mean	SD	Mean	SD
Al	152.8	107.5	93.5	15.5
Ba	2304.3	4533.0	149.8	69.5
Mn	1177.2	1341.0	248.3	183.6
Si	139.3	149.6	91.8	16.6
Ti	251.5	316.0	286.3	380.0
V	345.0	247.0	147.6	66.8
Y	120.5	42.4	87.5	12.6
Zr	80.6	43.7	54.6	33.4

Source: Adapted from Calabrese et al. (1989).

Table 5-5. Soil and Dust Ingestion Estimates for Children Ages 1-4 Years

		Intake (mg/day)[a]				
Tracer Element	N	Mean	Median	SD	95th Percentile	Maximum
Aluminum						
soil	64	153	29	852	223	6,837
dust	64	317	31	1,272	506	8,462
soil/dust combined	64	154	30	629	478	4,929
Silicon						
soil	64	154	40	693	276	5,549
dust	64	964	49	6,848	692	54,870
soil/dust combined	64	483	49	3,105	653	24,900
Yttrium						
soil	62	85	9	890	106	6,736
dust	64	62	15	687	169	5,096
soil/dust combined	62	65	11	717	159	5,269
Titanium						
soil	64	218	55	1,150	1,432	6,707
dust	64	163	28	659	1,266	3,354
soil/dust combined	64	170	30	691	1,059	3,597

[a]Corrected for Tracer Concentrations in Foods

Source: Adapted from Calabrese et al. (1989).

Table 5-6. Average Daily Soil Ingestion Values Based on Aluminum, Silicon, and Titanium as Tracer Elements[a]

Element	Mean (mg/d)	Median (mg/d)	Standard Error of the Mean (mg/d)	Range (mg/d)[b]
Aluminum	38.9	25.3	14.4	279.0 to 904.5
Silicon	82.4	59.4	12.2	-404.0 to 534.6
Titanium	245.5	81.3	119.7	-5,820.8 to 6,182.2
Minimum	38.9	25.3	12.2	-5,820.8
Maximum	245.5	81.3	119.7	6,182.2

[a]Excludes three children who did not provide any samples (N=101).
[b]Negative values occurred as a result of correction for nonsoil sources of the tracer elements.

Source: Adapted from Davis et al. (1990).

Table 5-7. Geometric Mean (Gm) and Standard Deviation (Gsd) Ltm Values for Children at Daycare Centers and Campgrounds

		Daycare Centers			Campgrounds		
Age (yrs)	Sex	n	GM LTM (mg/day)	GSD LTM (mg/day)	n	GM LTM (mg/day)	GSD LTM (mg/day)
<1	Girls	3	81	1.09	-	-	-
	Boys	1	75	-	-	-	-
1-<2	Girls	20	124	1.87	3	207	1.99
	Boys	17	114	1.47	5	312	2.58
2-<3	Girls	34	118	1.74	4	367	2.44
	Boys	17	96	1.53	8	232	2.15
3-4	Girls	26	111	1.57	6	164	1.27
	Boys	29	110	1.32	8	148	1.42
4-<5	Girls	1	180	-	19	164	1.48
	Boys	4	99	1.62	18	136	1.30
All girls		86	117	1.70	36	179	1.67
All boys		72	104	1.46	42	169	1.79
Total		162[a]	111	1.60	78[b]	174	1.73

[a]Age and/or sex not registered for eight children.
[b]Age not registered for seven children.

Source: Adapted from Van Wijnen et al. (1990).

Table 5-8. Estimated Geometric Mean Ltm Values of Children Attending Daycare Centers According to Age, Weather Category, and Sampling Period

Weather Category	Age (years)	First Sampling Period n	First Sampling Period Estimated Geometric Mean LTM Value (mg/day)	Second Sampling Period n	Second Sampling Period Estimated Geometric Mean LTM Value (mg/day)
Bad (>4 days/week precipitation)	<1	3	94	3	67
	1-<2	18	103	33	80
	2-<3	33	109	48	91
	4-<5	5	124	6	109
Reasonable (2-3 days/week precipitation)	<1			1	61
	1-<2			10	96
	2-<3			13	99
	3-<4			19	94
	4-<5			1	61
Good (<2 days/week precipitation)	<1	4	102		
	1-<2	42	229		
	2-<3	65	166		
	3-<4	67	138		
	4-<5	10	132		

Source: Van Wijnen et al. (1990).

Table 5-9. Distribution of Average (Mean) Daily Soil Ingestion Estimates per Child for 64 Children[a] (Mg/day)

Type of Estimate Number of Samples	Overall (64)	A1 (64)	Ba (33)	Mn (19)	Si (63)	Ti (56)	V (52)	Y (61)	Zr (62)
Mean	179	122	655	1,053	139	271	112	165	23
25th Percentile	10	10	28	35	5	8	8	0	0
50th Percentile	45	19	65	121	32	31	47	15	15
75th Percentile	88	73	260	319	94	93	177	47	41
90th Percentile	186	131	470	478	206	154	340	105	87
95th Percentile	208	254	518	17,374	224	279	398	144	117
Maximum	7,703	4,692	17,991	17,374	4,975	12,055	845	8,976	208

[a]For each child, estimates of soil ingestion were formed on days 4-8 and the mean of these estimates was then evaluated for each child. The values in the column "overall" correspond to percentiles of the distribution of these means over the 64 children. When specific trace elements were not excluded via the relative standard deviation criteria, estimates of soil ingestion based on the specific trace element were formed for 108 days for each subject. The mean soil ingestion estimate was again evaluated. The distribution of these means for specific trace elements is shown.

Source: Stanek and Calabrese (1995a).

Table 5-10. Estimated Distribution of Individual Mean Daily Soil Ingestion Based on Data for 64 Subjects Projected over 365 Days[a]

Range	1 - 2,268 mg/d[b]
50th Percentile (median)	75 mg/d
90th Percentile	1,190 mg/d
95th Percentile	1,751 mg/d

[a] Based on fitting a log-normal distribution to model daily soil ingestion values.
[b] Subject with pica excluded.

Source: Stanek and Calabrese (1995a).

Table 5-11. Estimated Soil Ingestion Rate Summary Statistics
And Parameters for Distributions Using Binder et Al. (1986)
Data with Actual Fecal Weights

	Soil Intake (mg/day)			
Trace Element Basis	A1	Si	Ti	MEAN[a]
Mean	97	85	1,004	91
Min	11	10	1	13
10th	21	19	3	22
20th	33	23	22	34
30th	39	36	47	43
40th	43	52	172	49
Med	45	60	293	59
60th	55	65	475	69
70th	73	79	724	92
80th	104	106	1,071	100
90th	197	166	2,105	143
Max	1,201	642	14,061	921
	Lognormal Distribution Parameters			
Median	45	60	--	59
Standard Deviation	169	95	--	126
Arithmetic Mean	97	85	--	91
	Underlying Normal Distribution Parameters			
Mean	4.06	4.07	--	4.13
Standard Deviation	0.88	0.85	--	0.80

[a] MEAN = arithmetic average of soil ingestion based on aluminum and silicon.

Source: Thompson and Burmaster (1991).

Table 5-12. Positive/negative Error (Bias) in Soil Ingestion Estimates in the Calabrese et Al. (1989) Mass-balance Study: Effect on Mean Soil Ingestion Estimate (Mg/day)[a]

	Negative Error						
	Lack of Fecal Sample on Final Study Day	Other Causes[b]	Total Negative Error	Total Positive Error	Net Error	Original Mean	Adjusted Mean
Aluminum	14	11	25	43	+18	153	136
Silicon	15	6	21	41	+20	154	133
Titanium	82	187	269	282	+13	218	208
Vanadium	66	55	121	432	+311	459	148
Yttrium	8	26	34	22	-12	85	97
Zirconium	6	91	97	5	-92	21	113

[a]How to read table: for example, aluminum as a soil tracer displayed both negative and positive error. The cumulative total negative error is estimated to bias the mean estimate by 25 mg/day downward. However, aluminum has positive error biasing the original mean upward by 43 mg/day. The net bias in the original mean was 18 mg/day positive bias. Thus, the original 156 mg/day mean for aluminum should be corrected downward to 136 mg/day.

[b]Values indicate impact on mean of 128-subject-weeks in milligrams of soil ingested per day.

Source: Calabrese and Stanek (1995).

Table 5-13. Soil Ingestion Estimates for Median and Best Four Trace Elements Based on Food/Soil Ratios for 64 Anaconda Children (mg/day) Using Al, Si, Ti, Y, and Zr

	Min	P5	P10	SP25	P50	SP75	P90	P95	Max	Mean	SD
Median of best 4	-101.3	-91.0	-53.8	-38.0	-2.4	26.8	73.1	159.8	380.2	6.8	74.5
Best tracer	-53.4	-24.4	-14.4	2.2	20.1	68.9	223.6	282.4	609.9	65.5	120.3
2nd best	-115.9	-62.1	-48.6	-26.6	1.5	38.4	119.5	262.3	928.5	33.2	144.8
3rd best	-170.5	-88.9	-67.0	-52.0	-18.8	25.6	154.7	376.1	1293.5	31.2	199.6
4th best	-298.3	-171.0	-131.9	-74.7	-29.3	0.2	74.8	116.8	139.1	-34.6	79.7

Source: Calabrese et al. (1997).

Table 5-14. Dust Ingestion Estimates for Median and Best Four Trace Elements Based on Food/Soil Ratios for 64 Anaconda Children (mg/day) Using Al, Si, Ti, Y, and Zr

	Min	P5	P10	SP25	P50	SP75	P90	P95	Max	Mean	SD
Median of best 4	-261.5	-186.2	-152.7	-69.5	-5.5	62.8	209.2	353.0	683.9	16.5	160.9
Best tracer	-377.0	-193.8	-91.0	-20.8	26.8	198.1	558.6	613.6	1499.4	127.2	299.1
2nd best	-239.8	-147.2	-137.1	-59.1	7.6	153.1	356.4	409.5	1685.1	82.7	283.6
3rd best	-375.7	-247.5	-203.1	-81.7	-14.4	49.4	406.5	500.5	913.2	25.5	235.9
4th best	-542.7	-365.6	-277.7	-161.5	-55.1	52.4	277.3	248.8	6120.5	81.8	840.3

Source: Calabrese et al. (1997).

Table 5-15. Daily Soil Ingestion Estimation in a Soil-pica Child by Tracer and by Week (mg/day)

Tracer	Week 1 Estimated Soil Ingestion	Week 2 Estimated Soil Ingestion
Al	74	13,600
Ba	458	12,088
Mn	2,221	12,341
Si	142	10,955
Ti	1,543	11,870
V	1,269	10,071
Y	147	13,325
Zr	86	2,695

Source: Calabrese et al. (1991).

Table 5-16. Ratios of Soil, Dust, and Residual Fecal Samples in the Soil Pica Child

Tracer Ratio Pairs		Soil	Fecal	Dust	Estimated % of Residual Fecal Tracers of Soil Origin as Predicted by Specific Tracer Ratios
1.	Mn/Ti	208.368	215.241	260.126	87
2.	Ba/Ti	187.448	206.191	115.837	100
3.	Si/Ti	148.117	136.662	7.490	92
4.	V/Ti	14.603	10.261	17.887	100
5.	Ai/Ti	18.410	21.087	13.326	100
6.	Y/Ti	8.577	9.621	5.669	100
7.	Mn/Y	24.293	22.373	45.882	100
8.	Ba/Y	21.854	21.432	20.432	71
9.	Si/Y	17.268	14.205	1.321	81
10.	V/Y	1.702	1.067	3.155	100
11.	Al/Y	2.146	2.192	2.351	88
12.	Mn/Al	11.318	10.207	19.520	100
13.	Ba/Al	10.182	9.778	8.692	73
14.	Si/Al	8.045	6.481	0.562	81
15.	V/Al	0.793	0.487	1.342	100
16.	Si/V	10.143	13.318	0.419	100
17.	Mn/Si	1.407	1.575	34.732	99
18.	Ba/Si	1.266	1.509	15.466	83
19.	Mn/Ba	1.112	1.044	2.246	100

Source: Calabrese and Stanek (1992).

Table 5-17. Daily variation of Soil Ingestion by Children Displaying Soil Pica in Wong (1988)

Child subject number	Month	Estimated soil ingestion (mg/day)
Glenhope Place of Study		
Number 11	1	55
	2	1,447
	3	22
	4	40
Number 12	1	0
	2	0
	3	7,924
	4	192
Number 14	1	1,016
	2	464
	3	2,690
	4	898
Number 18	1	30
	2	10,343
	3	4,222
	4	1,404
Number 22	1	0
	2	--
	3	5,341
	4	0
Reddles Place of Study		
Number 27	1	48,314
	2	60,692
	3	51,422
	4	3,782

Source: Calabrese and Stanek (1993).

Table 5-18. Prevalence of Non-Food Ingestion/Mouthing Behaviors by Child's Age: Percent of Children Whose Parents Reports the Behavior in the Past Month

Non-Food Ingestion/mouthing prevalence		Child's Age (years) 1	2	3	4	5	6	All
	N	171	70	93	82	90	22	528
Outdoor "soil" mouthing/Ingestion								
Sand, stones	% > Monthly	54	26	19	9	7	9	27
	% > Weekly	36	10	6	2	4	5	16
	% Daily	17	0	2	1	1	5	6
Grass, leaves, flowers	% > Monthly	48	16	24	13	9	5	26
	% > Weekly	34	7	14	4	6	0	16
	% Daily	16	0	2	1	1	0	6
Twigs, sticks, woodchips	% > Monthly	42	23	13	13	11	5	23
	% > Weekly	29	7	9	5	7	0	14
	% Daily	12	0	0	1	0	0	4
Soil, dirt	% > Monthly	38	21	5	7	3	9	18
	% > Weekly	24	7	3	2	1	9	10
	% Daily	11	0	1	0	1	0	4
Dust, lint, dustballs	% > Monthly	14	4	2	0	0	5	6
	% > Weekly	7	1	1	0	0	0	3
	% Daily	2	0	0	0	0	0	1
Plaster, chalk	% > Monthly	8	10	3	2	3	5	5
	% > Weekly	5	3	0	1	0	0	2
	% Daily	2	0	0	1	0	0	1
Paintchips, splinters	% > Monthly	6	0	0	4	1	0	3
	% > Weekly	2	0	0	1	0	0	1
	% Daily	0	0	0	0	0	0	0
General mouthing of objects								
Other toys	% > Monthly	88	53	64	44	42	23	62
	% > Weekly	82	44	42	26	28	9	49
	% Daily	63	27	20	9	7	5	30
Paper, cardboard, tissues	% > Monthly	71	37	32	23	18	14	41
	% > Weekly	54	23	20	12	7	9	28
	% Daily	28	9	8	5	2	5	13
Teething toys	% > Monthly	65	29	15	4	3	9	29
	% > Weekly	55	16	9	1	1	9	22
	% Daily	44	6	6	0	0	9	17

Table 5-18. Prevalence of Non-Food Ingestion/Mouthing Behaviors by Child's Age: Percent of Children Whose Parents Reports the Behavior in the Past Month (continued)

Crayons, pencils, erasers	% > Monthly	56	54	46	50	41	36	50
	% > Weekly	41	37	25	27	26	27	32
	% Daily	19	17	4	6	4	18	12
Blankets, cloth	% > Monthly	51	21	26	22	22	14	32
	% > Weekly	42	17	17	18	14	14	25
	% Daily	29	11	9	13	7	5	16
Shoes, Footware	% > Monthly	50	23	8	7	2	5	22
	% > Weekly	42	10	3	2	1	5	16
	% Daily	20	1	0	0	0	0	7
Clothing	% > Monthly	49	34	37	43	26	27	39
	% > Weekly	39	24	23	28	16	14	27
	% Daily	25	7	11	9	6	14	14
Other items	% > Monthly	41	30	30	23	21	27	31
	% > Weekly	35	26	24	15	10	14	23
	% Daily	22	11	15	7	6	5	14
Crib, chairs, furniture	% > Monthly	37	11	8	10	4	5	17
	% > Weekly	26	9	3	5	2	0	11
	% Daily	13	3	1	1	0	0	5
Sucking of fingers, etc								
Suck fingers/thumb	% > Monthly	67	41	43	57	39	41	52
	% > Weekly	60	27	31	43	31	18	41
	% Daily	44	21	22	26	24	14	30
Suck feet or toes	% > Monthly	37	14	12	11	3	0	18
	% > Weekly	23	4	3	2	1	0	9
	% Daily	8	1	0	1	0	0	3
Use pacifier	% > Monthly	24	9	6	2	2	5	11
	% > Weekly	22	9	5	2	2	0	10
	% Daily	20	6	5	1	1	0	9
Suck hair	% > Monthly	1	3	8	9	10	5	5
	% > Weekly	1	3	2	2	4	5	2
	% Daily	1	1	1	0	2	0	1

Table 5-18. Prevalence of Non-Food Ingestion/Mouthing Behaviors by Child's Age: Percent of Children Whose Parents Reports the Behavior in the Past Month (continued)

"Disgusting" object mouthing/ingestion								
Soap, detergent, shampoo	% > Monthly	48	34	24	17	9	9	29
	% > Weekly	37	27	14	11	6	9	21
	% Daily	15	14	3	2	0	0	8
Plastic, plastic wrap	% > Monthly	32	19	8	7	9	0	17
	% > Weekly	22	11	3	4	4	0	10
	% Daily	7	4	1	0	1	0	3
Cigarette butts, tobacco	% > Monthly	16	6	5	4	3	5	8
	% > Weekly	10	4	4	1	2	5	5
	% Daily	4	0	1	1	1	0	2
Matches	% > Monthly	6	4	1	4	1	0	4
	% > Weekly	2	3	1	1	1	0	2
	% Daily	1	0	0	0	0	0	0
Insect	% > Monthly	5	1	2	4	2	0	3
	% > Weekly	2	0	1	4	2	0	2
	% Daily	0	0	1	2	2	0	1
Other ingestion and behaviors								
Toothpaste	% > Monthly	63	97	92	94	93	86	84
	% > Weekly	60	94	91	93	92	86	82
	% Daily	52	87	86	93	89	82	77
Chew gum	% > Monthly	18	56	76	76	91	100	58
	% > Weekly	10	40	60	60	69	68	43
	% Daily	3	17	18	13	21	36	14
Bite nails	% > Monthly	8	26	31	29	33	59	24
	% > Weekly	5	23	24	20	26	45	18
	% Daily	2	7	12	9	10	14	7
Suck hair	% > Monthly	62	76	85	96	88	73	78
	% > Weekly	57	64	77	88	81	68	71
	% Daily	42	39	43	55	52	45	45

Source: Stanek et al. (1998).

Table 5-19. Average Outdoor Object Mouthing Scores for Children by Age, Frequency of Sand/Dirt Play, and General Mouthing Quartiles

Outdoor object mouthing scores	1 Year old Sand/dirt play?				Age 2 to 6 years Sand/dirt play?			
	>Daily		Daily		>Daily		Daily	
	Mean	N	Mean	N	Mean	N	Mean	N
General mouthing Score quartiles (Mean)								
1st Quartile (1.5)	0.1	19	2.8	16	0.1	139	0.5	117
2nd Quartile (9.7)	0.7	14	3.9	11	0.3	27	0.8	28
3rd Quartile (19.6)	1.3	33	10.5	22	0.2	19	1.8	21
4th Quartile (35.6)	3.6	35	14	23	0.5	2	1.5	4
Slope based on general mouthing quartile score	0.11		0.34		0.007		0.054	
SE	0.052		0.060		0.021		0.019	

Source: Stanek et al. (1998).

Table 5-20. Summary of Estimates of Soil Ingestion by Children

Mean (mg/day)					Upper Percentile (mg/day)				References
Al	Si	AIR[a]	Ti	Y	Al	Si	Ti	Y	
181	184				584	578			Binder et al. 1986
230		129							Clausing et al. 1987
39	82		245.5						Davis et al. 1990
64.5[b]	160[b]		268.4[b]						
153	154		218	85	223	276	1,432	106	Calabrese et al. 1989
154[b]	483[b]		170[b]	65[b]	478[b]	653[b]	1,059[b]	159[b]	
122	139	–	271	165	254	224	279	144	Stanek and Calabrese, 1995a
133[c]					217[c]				Stanek and Calabrese, 1995b
69-120[d]									Van Wïjnen et al. 1990
66[c]					280[c]				Calabrese et al. 1997
196[b]					994[b]				
Average = 138 mg/day soil					358 mg/day soil				
193 mg/day soil and dust combined					790 mg/day soil and dust combined				

[a]AIR = Acid Insoluble Residue
[b]Soil and dust combined
[c]BTM
[d]LTM; corrected value

Table 5-21. Summary of Recommended Values for Soil Ingestion

Population	Mean	Upper Percentile
Children (age 1-6 years)	100 mg/day[a]	400 mg/day[b]
Pica child	10 g/day[c]	---

[a]200 mg/day may be used as a conservative estimate of the mean (see text).
[b]Study period was short; therefore, these values are not estimates of usual intake.
[c]To be used in acute exposure assessments. Based on only one pica child (Calabrese et al., 1989).

Table 5-22. Confidence in Soil Intake Recommendation

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	All key studies are from peer review literature.	High
• Accessibility	Papers are widely available from peer review journals.	High
• Reproducibility	Methodology used was presented, but results are difficult to reproduce.	Medium
• Focus on factor of interest	The focus of the studies was on estimating soil intake rate by children; studies did not focus on intake rate by adults.	High (for children) Low (for adults)
• Data pertinent to U.S.	Two of the key studies focused on Dutch children; other studies used children from specific areas of the U.S.	Medium
• Primary data	All the studies were based on primary data.	High
• Currency	Studies were conducted after 1980.	High
• Adequacy of data collection period	Children were not studied long enough to fully characterize day to day variability.	Medium
• Validity of approach	The basic approach is the only practical way to study soil intake, but refinements are needed in tracer selection and matching input with outputs. The more recent studies corrected the data for sources of the tracers in food. There are, however, some concerns about absorption of the tracers into the body and lag time between input and output.	Medium
• Study size	The sample sizes used in the key studies were adequate for children. However, only few adults have been studied.	Medium (for children) Low (for adults)
• Representativeness of the population	The study population may not be representative of the U.S. in terms of race, socio-economics, and geographical location; Studies focused on specific areas; two of the studies used Dutch children.	Low
• Characterization of variability	Day-to-day variability was not very well characterized.	Low
• Lack of bias in study design (high rating is desirable)	The selection of the population studied may introduce some bias in the results (i.e., children near a smelter site, volunteers in nursery school, Dutch children).	Medium
• Measurement error	Errors may result due to problems with absorption of the tracers in the body and mismatching inputs and outputs.	Medium
Other Elements		
• Number of studies	There are 7 key studies.	High
• Agreement between researchers	Despite the variability, there is general agreement among researchers on central estimates of daily intake for children.	Medium
Overall Rating	Studies were well designed; results were fairly consistent; sample size was adequate for children and very small for adults; accuracy of methodology is uncertain; variability cannot be characterized due to limitations in data collection period. Insufficient data to recommend upper percentile estimates for both children and adults.	**Medium** (for children - long-term central estimate) **Low (**for adults) **Low** (for upper percentile)